EVALUATING RELIABILITY OF ELECTRONIC COMPONENTS IN VEHICLES BY ACCELERATED RELIABILITY TESTING

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Abstract

This paper presents an accelerated reliability testing method for evaluating the reliability of electronic components. Due to their gradually common applications in vehicles, light-emitting diodes are used to conduct experiments. In these tests, temperature and humidity are the two genres of environmental stress considered. While the former type is the accelerated stress (at 70°C, 90°C and 100°C), the later is kept under normal operating conditions (80% RH). The research indicates that accelerated reliability testing is a suitable method to quickly obtain reliability parameters of electronic components. Besides, for electronic components that show degradation characteristics during the test, test duration, as well as expenditure, can be lower by testing obtaining degradation parameters instead of testing until the component is completely broken (test duration has been reduced from over 9400 hours to 2668 hours).

Keywords: *Accelerated reliability testing; electronic component; reliability; degradation analysis; failure data.*

1. Introduction

In recent years, reliability of electronic components has been estimated by using the standard handbook, similarity analysis method based on operation & maintenance data (reliability database) or performing accelerated reliability testing (ART) [1]. In general, the use of standard handbooks (e.g. MIL-HDBK-217, RIAC-217, PRISM) [2, 3], and reliability database (e.g. EPRD-2G14, FMD-2G16) [4], imposes some inherent limitations. For example, these two methods which are based on assumptions about a constant failure rate may incorrectly reflect the failure trend in the product life cycle; the methods cannot indicate basic failure mechanisms and do not provide the root cause of failure; the methods are not effective in predicting the reliability of newly manufactured electronic components, etc. Hence, in order to obtain failure data of electronic components for analysing their failure modes and understanding life characteristics in a short period of time, another approach has been developed, i.e. ART. The ART based on physics-of-failure approach provides complete

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information about the various degradation mechanisms and causes of failure, thereby providing insight into the reliability of electronic components. This method has become increasingly important because of the need to develop more modern products, a shorter period from product design to product release while productivity, quality, and reliability are assured.

ART is a test in which stress level, or rate of stress application, exceeds that occurring under specified operational conditions, to reduce the duration required to produce a stress response [5].

The purpose of ART is to identify potential design weaknesses, to estimate the reliability of the product at normal operating condition, or to record the necessary improvement of reliability within an accelerated period of time. The basic principle of ART is the effect of stress on reducing life expectancy. Therefore, the strategy in the accelerated testing is to increase the stress level under the test, cumulative damage is equivalent to the expected life of the product for the type of expected stress [6]. ART helps to determine the reliability of products relative to certain defect mechanisms in operating conditions, thereby providing details of failure mechanisms and improving understanding of the root cause of the failure.

The ART procedure for electronic components in vehicles can be expressed as follows [5]:

• Determine the relevant stress factors from the operating conditions of vehicles, including operation and storage;

• Determine which type of stress must be accelerated, which will be nominal and which can be ignored. These stresses can be applied simultaneously or sequentially;

• Determine the number of stress levels and sample size;

• Decide the testing plan and design of test system;

• Perform the ART;

• Analyse the test data.

The test results obtained are normally data on failure time of electronic components. In this case, accelerated life data analysis can be used to estimate reliability parameters. However, in the event that the test process has not yet obtained this data, it only yielded data about its degradation, degradation analysis is applied.

This article describes the methodology to evaluate reliability of electronic components in vehicles by degradation analysis of ART data. Light-emitting diodes (LEDs) are used to conduct experiments because of their gradually common applications in vehicles [7, 8].

2. Stress factors of electronic components in vehicles

The types of stress for ART of electronic components in vehicles include temperature, thermal cycling, heat shock, humidity, voltage, current, mechanical stress (vibration, shock) and combination of stresses. In this study, two types of environmental stress are considered, i.e. temperature and humidity.

The first factor, temperature, can be considered the enemy of reliability of electronic components. Most electronic components are susceptible to damage at high temperatures (overheating) and their reliability is influenced by its operating temperature. Therefore, the process of analysing system errors of electronic components usually involves examining evidence or signs of overheating. Studies have also shown that there is a relationship between the performance as well as lifetime or life cycle of an electronic component and its specific operating temperature range. In deed, the temperature can basically determines the effective performance and the lifetime of electronic components. The temperatures of electronic component include the temperature of the environment (generated by the direct influence of solar radiation and heat exchange) and the temperature generated when the device is in operation. For example, heat source is generated by engine or actions of friction, it is transmitted from mechanical energy to heat; the conductors emit heat when the current passes through, etc. High and low temperatures can make electronic components unsafe for use because they change the characteristics of materials in the construction of electronic components [9].

The second factor mentioned is relative humidity which also negatively affects electronic components. Relative humidity is the ratio between the vapour pressure of water contained in the air and the saturating vapour pressure. When humidity is more than 80%, it reduces the quality of materials, moisture penetrates into the material or form a damp membrane on the surface of the material. When humidity in the air is low (less than 40%), moisture from the material evaporates in the air, leading to changes in the materials of electronic components and making them fragile and cracks appear [9]. The common failure modes caused by humidity are corrosion and short circuit. Since electronic components operate at high temperatures, corrosion process increases. Hence the combination of temperature and humidity is frequently applied in ART.

In this paper, specific temperature and humidity stress factors on vehicles in Vietnam are as follows [10]: The ambient temperature is between 20°C to 30°C with the average temperature at 25°C and the daily variations of temperature is 10°C. When electronic systems are switched on, the temperature increases from ambient temperature (25°C) up to 35°C due to its heat dissipation. The relative humidity in use is 80%.

3. Design of accelerated reliability testing

3.1. Test samples

The experiment was conducted on high-power white LED 3W- GT P03W5 (GeTian Opto-electronics). The structure of the high-power LED is shown in Fig. 1, includes lead frame plastic packaging with spherical polycarbonate (PC) lens and the InGaN/GaN LED chip (1 mm^2 size) attached to Al ground substrate as heat sink. LEDs are mounted on an aluminium board 400 x 100 x 5 mm, 6-LED groups are connected in series, with an access to the anode and cathode of each one provided by a special contact (as shown in Fig. 2). The 78-Pin D-Sub Connector is used to gather the wires of each group of LEDs so that it is possible to easily connect and disconnect each device from the measuring system. Each group of LEDs are supplied constant currents by the high precision digital DC power unit. Tab. 1 describes electrical-optical characteristics of LED at ambient temperature of 25°C.

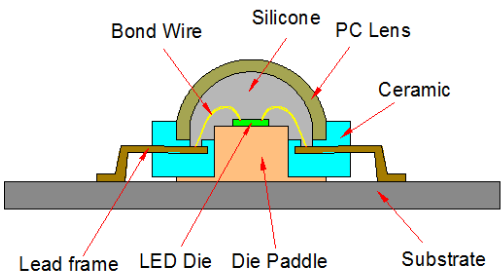

Fig. 1. Schematic structure of LED 3W

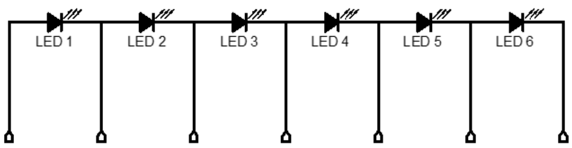

Fig. 2. Electrical configuration of LEDs

Tab. 1. Electrical-optical characteristics of LED 3W

Parameter	Symbol	Min	Typ	Max	Unit
Luminous Flux	Φv	240	~	260	lm
Correlated Color Temperature	*CCT*	2900	~	3200	K
Color Rendering Index (CRI)	*Ra*	60	~	90	~
Forward Voltage	V_F	3.3	~	4	V
Power Dissipation	P_D	2.48	~	3.0	W
View Angle	$2\theta 1/2$	~	120	~	deg.
Thermal Resistance	$R\theta_{j\text{-}B}$	~	12	~	°C/W

3.2. Test conditions

The operational conditions of vehicles consist of two different phases:

• Operating days: 305 days per year with operating time of 8 hours per day. The total duration of the phase is 3660 hours per year (305 × 24 hours).

• Non-operating days: 60 days per year. The total duration of this phase is 1440 hours per year (60 × 24 hours). The environmental stress conditions are shown in Tab. 2.

Tab. 2. Environmental stress conditions of electronic components

Parameter	Symbol	Value (unit)
Required life	t_0	15 years = 131400 h
Required reliability	$R(t)$	≥ 0.8
Time - ON	t_{on}	8 h/day, 305 day/year = 36600 h
Time - OFF	t_{off}	94800 h
Temperature - ON	T_{on}	35°C
Temperature - OFF	T_{off}	25°C
Temperature change	ΔT_{use}	10°C
Relative humidity	RH_{usse}	80%

The combination of temperature and humidity is used in this ART, temperature is the accelerated stress (at 70°C, 90°C and 100°C) while the humidity is kept under the normal operating conditions (80% RH). The number of LED samples corresponding to each stress level is 12. The test is terminated at a pre-assigned test duration ($\tau = \tau_0$), the number of failures r is a random variable. The failed units under test are not replaced by new ones **[n, U, τ_0]** (as shown in Fig. 3).

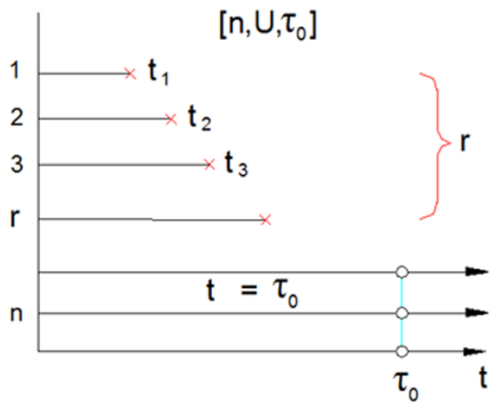

Fig. 3. Test plan [11]

In this case, test duration is τ_{01} = 1152 hours (48 days) for temperature conditions of 70°C, τ_{02} = 960 hours (40 days) for temperature conditions of 90°C and for temperature conditions of 100°C, test duration is τ_{03} = 576 hours (24 days).

Tab. 3. Test conditions

Temperature T (°C)	Current I (mA)	Humidity RH (%)	Test duration τ_0 (h)	Sample size n
70	750	80	1152	12
90	750	80	960	12
100	750	80	576	12

3.3. Experimental setup

The experimental setup for the ART of the high-power LEDs is shown in Fig. 4. The LEDs were placed in the climate chamber Vötsch VC3 7034. The LEDs then were connected to the DC power supply (Keysight E3634A) and measure unit (Keysight 34980A Multifunction Switch/Measure Unit). The LEDs are supplied constant currents, and voltage in each LED was measured every 10 minutes. The measured values were continuously recorded using a PC with software. Optical power (power luminosity) was measured at a constant current of 750 mA by using a one-meter diameter integrating sphere (UMBB-1000) and a spectroradiometer (OL770).

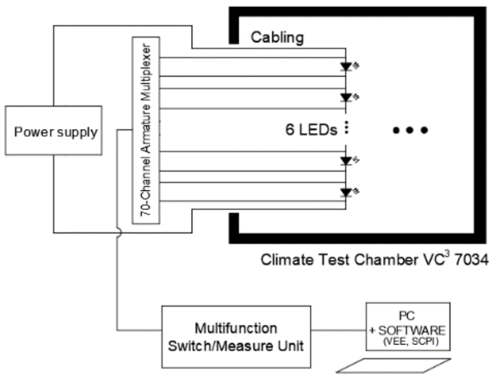

Fig. 4. Experimental arrangements

4. Evaluation of test results

In these tests, no failure occurs during the test time (τ_{01}, τ_{02}, τ_{03}). These test results were comprised of degradation data which were then extrapolated using a suitable degradation model to obtain time to failures at each of the temperature levels (70ºC, 90ºC, 100ºC). The failure time was determined based on establishing a failure threshold for the degradation characteristic measured (through extrapolation using degradation analysis). The measured data here were the degradation of optical power of LEDs. The optical power degradation measured during testing is plotted in Fig. 5 (3 LEDs at each stress level).

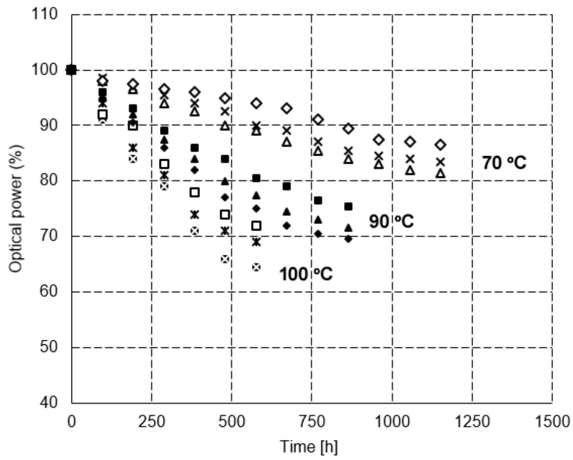

Fig. 5. Optical power degradation at different times and temperatures

The degradation over time of the optical power of LEDs was exponential in nature. Therefore, the light output L can be expressed as follows [12]:

$$L = L_0 e^{-\theta t} \tag{1}$$

where θ is the degradation constant obtained by data fitting.

The relationship (1) is linearized by taking the natural logarithm of both sides of the equation, which results in:

$$\ln\left(\frac{L}{L_0}\right) = -\theta t \tag{2}$$

The first step in degradation analysis is to fit (2) to each degradation path and estimate the parameters θ for each unit using the least squares method (LSM). Because the failure criteria of LED indicate that the LED is considered a failure if the optical power decreases exceed 50%. Thus, in next step we can calculate the approximate failure time of each test unit using equation:

$$t = \frac{\ln(2)}{\theta} \tag{3}$$

Fig. 6 shows the fits of the degradation model to the test data (at 70°C, 90°C, and 100°C) and indicates that the exponential degradation model is appropriate. The resulting failure time for 12 LEDs at each stress level is described in Tab. 4.

Based on failure data in Tab. 4, the next step is to select an appropriate probability distribution. Past experiments have shown that the majority of the test data collected at each stress levels can usually be appropriately fitted onto one of the underlying distributions, namely exponential, Weibull and lognormal distributions [13]. Maximum Likelihood Estimation (MLE) method was applied to estimate the parameters of these distributions. Then Anderson-Darling (AD) test is used to determine the optimum one of fit graphically [14]. The results indicated that Weibull distribution describes the data more appropriate than other distribution. The histograms at test conditions are constructed as shown in Fig. 7a, Fig. 7b, Fig. 7c.

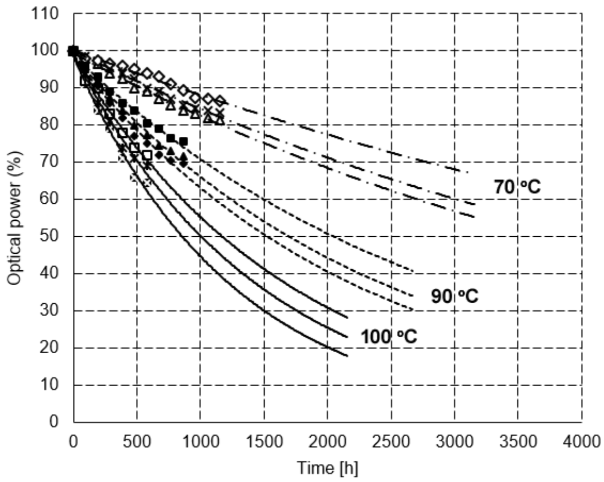

Fig. 6. Degradation model fitted to test data

Tab. 4. Failure time

No.	Failure time [h]		
	T_1 = 70°C	T_2 = 90°C	T_3 = 100°C
1	3832	1454	825
2	4001	1525	889
3	4572	1576	1025
4	4780	1598	1090
5	5164	1621	1108
6	5234	1664	1186
7	5411	1733	1195
8	5475	1792	1218
9	5528	1887	1282
10	5676	1905	1328
11	5819	1954	1332
12	5901	2143	1349

The probability density function (PDF) of the Weibull distribution of failure data is given by [15]:

$$f(t) = \frac{\beta}{\eta}\left(\frac{t}{\eta}\right)^{\beta-1} e^{-\left(\frac{t}{\eta}\right)^{\beta}} \tag{4}$$

where β is the shape parameter of the distribution, η is the scale parameter of the distribution.

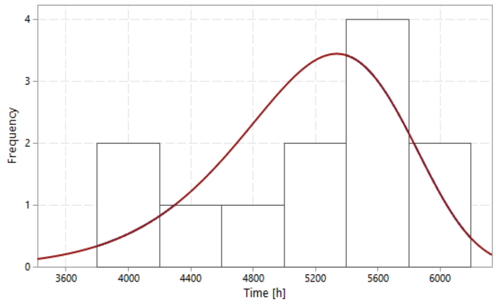

Fig. 7a. Histogram of the failure data at 70°C

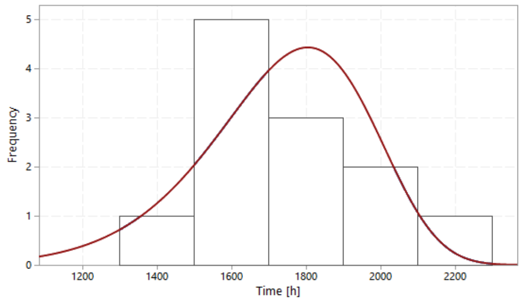

Fig. 7b. Histogram of the failure data at 90°C

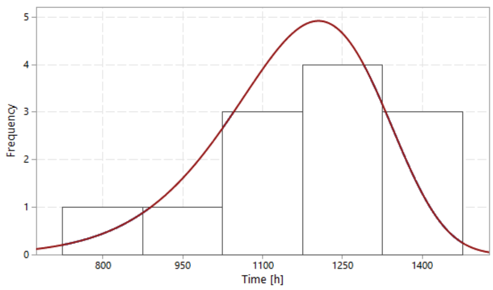

Fig. 7c. Histogram of the failure data at 100°C

Fig. 8 shows PDF of the Weibull distribution of failure data. The Weibull plots of the failure time at each temperature level yielded the estimates as $\hat{\eta}_1 = 5388$ and $\hat{\beta}_1 = 10.1$ for temperature of 70°C; $\hat{\eta}_2 = 1827$ and $\hat{\beta}_2 = 9.2$ for temperature of 90°C; $\hat{\eta}_3 = 1220$ and $\hat{\beta}_3 = 9.0$ for temperature of 100°C. The mean life (also called MTTF) is 5134 hours at 70°C, 1735 hours at 90°C and 1158 hours at 100°C.

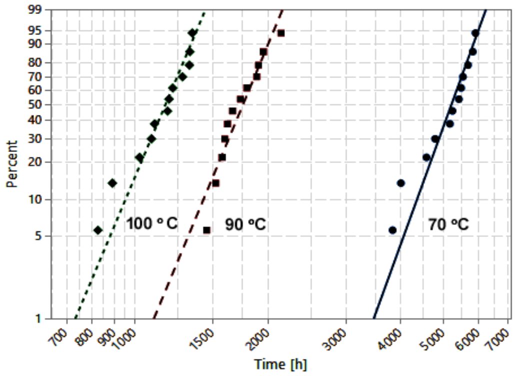

Fig. 8. The PDF of the Weibull distribution

Because the accelerated stress is temperature, the Arrhenius relationship can be used to extrapolate the reliability parameter at normal operating conditions [16]. The Arrhenius relationship and the Weibull distribution can be expressed as follows [17]:

$$\ln(\eta) = \alpha_0 + \alpha_1 x \tag{5}$$

where α_0 is the intercept of the line, α_1 is the slope of the line, and $x = 1/T$, T is absolute temperature (K).

According to (5), $\ln(\eta)$ is a linear function of $1/T$. Hence, the relationship $\ln(\eta_i)$ versus $1/T_i$ is plotted in a graph and then a regression line is fitted to the data points. The fit of the Arrhenius-Weibull relationship is shown in Fig. 9. Using the LSM, this relationship parameter obtained is α_0 = -10.076, α_1 = 6399.

The estimate of the Weibull scale parameter (η_0) at T_0 was given by [17]:

$$\eta_0 = e^{\left(\alpha_0 + \alpha_1 \frac{1}{T_0}\right)} \tag{6}$$

Thus, at 35°C (normally operational conditions of vehicles), the Weibull scale parameter is:

$$\eta_0 = e^{\left(-10.076 + 6399 \frac{1}{273+35}\right)} = 44355$$

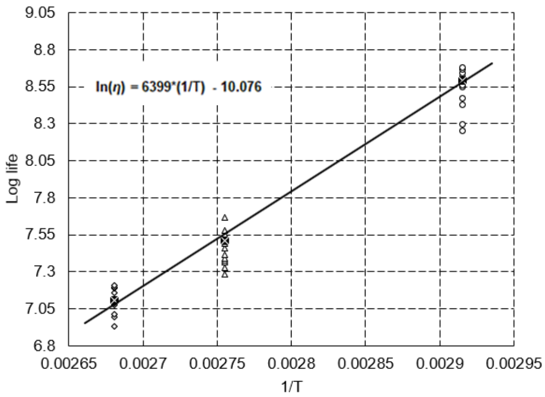

Fig. 9. Arrhenius-Weibull relationship plot for LEDs

The estimate of the Weibull shape parameter (β_0) is given by [17]:

$$\beta_0 = \frac{N_i \hat{\beta}_i}{\sum N_i} \tag{7}$$

where N_i is the number of failures at stress level $\boldsymbol{i}$.

With the number of failures $N_1 = N_2 = N_3 = 12$, the shape parameter of the Weibull in this case is:

$$\beta_0 = \frac{12 \times 9.0 + 12 \times 9.2 + 12 \times 10.1}{36} = 9.4$$

The MTTF of LEDs according to Arrhenius-Weibull relationship then is:

$$MTTF = \eta_0 \Gamma\left(\frac{1}{\beta_0} + 1\right) = 42084 \text{ hours}$$

This corresponds to approximately 17.2 years under given conditions of military vehicles. For require life of electronic components in military vehicles is 15 years.

The reliability of LEDs is:

$$R(t) = e^{-\left(\frac{t}{\eta_0}\right)^{\beta_0}} = 0.849$$

This means that probability of failure of the LEDs is 15.1% within 15 years of operation when used in vehicles.

5. Conclusion

This paper focused on design and practical conduct of an ART to evaluate the reliability of electronic components in vehicles. The paper also demonstrates a practical application of the proposed method in the case of LEDs, whose degradation is observed through the deterioration of light intensity. Today, electronic components become more reliable thanks to technology advance and manufacturing capabilities. Thus, ART may not yield failures within a given time and at the selected stress level. In these situations, in regard to electronic components whose performance characteristics degrade over time, reliability can be estimated by analysing degradation data. The deterioration of the characteristics indicates a decrease in reliability. Electronic components are said to fail when a performance characteristic exceeds a specific threshold. In particular situation of this paper, optical power is the degradation characteristic of LEDs and threshold value of degradation to determine the failure time is 50%. Exponential model is used as the basic mathematical model to extrapolate the performance measurements over time to the threshold value.

The results indicated that these LEDs are appropriate for use in vehicles, with MTTF up to 17.2 years. With the required life of 15 years for electronic components in vehicles, the reliability of LEDs is 0.849 (required reliability $R \geq 0.8$).

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ĐÁNH GIÁ ĐỘ TIN CẬY LINH KIỆN ĐIỆN TỬ TRÊN Ô TÔ BẰNG PHƯƠNG PHÁP THỬ NGHIỆM TĂNG CƯỜNG

Tóm tắt: *Bài báo trình bày phương pháp thử nghiệm tăng cường để đánh giá độ tin cậy của các linh kiện điện tử trên ô tô. Đèn LED được lựa chọn để tiến hành các thử nghiệm do đèn LED đang dần được sử dụng phổ biến trên ô tô. Trong các thử nghiệm này, nhiệt độ và độ ẩm là hai yếu tố môi trường được xem xét, trong đó nhiệt độ là yếu tố được tăng cường (với ba mức 70ºC, 90ºC, 100ºC), còn độ ẩm được giữ ở mức hoạt động bình thường (80% RH). Kết quả nghiên cứu chỉ ra rằng thử nghiệm tăng cường là một phương pháp hợp lý để nhanh chóng thu nhận tham số độ tin cậy của các linh kiện điện tử trên ô tô. Ngoài ra, với các linh kiện điện tử mà sự xuống cấp có thể xác định được trong quá trình thử nghiệm, thời gian và chi phí thử nghiệm có thể giảm xuống nhờ tiến hành các thử nghiệm tăng cường thu nhận thông số xuống cấp thay vì thử nghiệm đến khi linh kiện hỏng hoàn toàn (thời gian thử nghiệm giảm từ hơn 9400 giờ xuống còn 2668 giờ).*

Từ khóa: Thử nghiệm tăng cường; độ tin cậy; linh kiện điện tử; phân tích sự suy giảm; dữ liệu hư hại.

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